

Appendix H2 - Analysis of Pumping Tests

Following the field pumping tests, data from the 30-PSI rated pressure transducers (In-Situ Level TROLL® 700 Series) were downloaded and processed using WinSitu 5 software (In-Situ, Inc., 2007). The depth-to-water measurements were converted to drawdown in a spreadsheet. The plots of the drawdown and pumping rates versus time are included in this appendix.

Initial Assessment of the Test Results

The drawdown response to pumping in the extraction wells stabilized quickly at all the tested locations, indicating that the wells are installed in permeable aquifer material. The pumping test wells were selected along the main contaminant transport pathway from the former Omega property, at locations where future remedial pumping may be considered. These wells were screened in sand units that likely represent the most permeable aquifer material at OU2. The well screens were not installed in fine grained materials that comprise a significant portion of the sediments at OU2. Therefore, the aquifer properties estimated from the pumping tests are characteristic of the material within the main contaminant transport pathway, but not of the bulk aquifer properties in the basin.

The tests at nested wells and well clusters allowed the evaluation of hydraulic continuity of the aquifer near the tested wells. During the EW-1 pumping tests, all four well screens at MW8 were monitored. Wells MW-8A, MW-8B, and MW-8C responded to the pumping while well MW-8D did not. The drawdown responses and the model fitting discussed below indicated that the units screened by the upper three screens at MW8 (A-C) responded hydraulically as one aquifer. The aquifer zone screened by MW8D is separated by fine-grained sediments from the overlying unit. This conclusion is further supported by the difference in heads and contaminant concentrations measured in MW8D and those measured in the three shallower wells (MW8A-C).

During the pumping tests at nested wells (MW23A, MW24A, MW24C, MW26A, MW26B, MW27A, MW27B, and MW30), water levels in adjacent screen intervals (above and below, as applicable) were monitored with pressure transducers. Drawdown response was recorded at MW24B during pumping from MW24C, indicating hydraulic communication between the two screened zones. No other observation wells responded to pumping. These results indicate that the fine grained unit separating MW24B and MW24C is not an effective barrier to groundwater flow and contaminant migration. The fine grained unit between MW24A and MW24B likely is a barrier to groundwater flow, as evidenced by the lack of hydraulic response and also by the difference in head and contaminant concentrations. MW24C and MW24D are likely separated by a low permeability unit because no response to pumping from MW24C was recorded in MW24D.

Plots of drawdown (stabilized at the end of each pumping step) versus pumping rates can be found in this appendix. A linear trend implies no well loss due to friction at the well screen. This was observed at MW26B and MW30; therefore, the well loss coefficient C (e.g., Kawecki, 1995) was not included in the model fitting to the data from these two wells. For most tested wells the trend is non-linear (approximately quadratic), indicating the effect of frictional well loss; C was estimated via model fitting for these tests. The specific capacities

of the wells, shown in Table H2-1 were calculated as the pumping rate divided by the drawdown of the last step in the tests. The specific capacity, along with the drawdown versus pumping rate charts, will be used to predict the pumping rates for remedial alternatives evaluated as part of the future Feasibility Study.

Background water levels were monitored prior to the EW1 test. Monitoring of water levels during the tests at the nested wells provided additional background data. No significant trends in water levels were recorded during the test; consequently, no trend corrections of the time-drawdown data were necessary. The background monitoring showed diurnal, atmospheric pressure induced fluctuations of the water levels inside the wells with amplitude of up to 0.05 feet. These fluctuations constitute “noise” in the test data; because of their small magnitude, no correction was required.

Methods of Analysis

The pumping tests were performed at wells installed at highly permeable aquifer material and at locations of potential remedial pumping. The drawdown response was generally very fast and the water level in the pumped well stabilized early into the pumping. Such pumping response makes traditional methods for pumping test analysis (e.g., Kruseman and deRidder, 1992) difficult to use. Conducting the tests in steps provided further information on the well properties (well loss) as well as sufficient information content on aquifer properties, but required fitting with a model that also accounts for frictional well loss. Widely used commercial software (e.g., Aqtesolv, AquiferWin, etc.) includes methods for analyzing tests on partially penetrating wells with finite casing diameter, or fully penetrating wells experiencing well loss, but not both. Analysis with these methods resulted in systematic misfit between the model and field data (examples from MW23A and MW24A are shown in this appendix). The processed data were therefore analyzed using the General Well Function (GWF; Perina and Lee, 2006) for pumping from partially-penetrating wells installed in confined, unconfined, or leaky aquifers. GWF accounts for well skin properties; the well loss is included as an additional drawdown component (e.g., Kawecki, 1995). The fitting of the model to the observed time-drawdown data was using the non-linear least squares technique based on the modified Marquardt method. The plots of observed and computed time-drawdown data are included in this appendix.

Estimated Aquifer Properties

The main objective was to estimate the horizontal hydraulic conductivity of the aquifer zones screened by the tested wells. The specific storage (S_s) and the hydraulic conductivity in the vertical direction (K_z) could not be reliably estimated from the test data; this is a known limitation of single-well pumping tests (e.g., Kruseman and deRidder, 1994).

However, S_s can be constrained within a fairly narrow range for unconsolidated sandy soils using published values of soil compressibility and porosity (Domenico and Schwartz, 1992); the range of plausible S_s values is shown in Table H1-2 (in Appendix H-1). The lowest estimated S_s value of 1.0×10^{-6} ft⁻¹ is lower than the reasonable range of S_s values from 9.9×10^{-6} ft⁻¹ to 2.69×10^{-4} ft⁻¹ for sands and gravels (Domenico and Schwartz, 1990). Therefore, for most tests, S_s was held fixed (not estimated) at a value of 4.0×10^{-5} ft⁻¹. This S_s value was chosen to be more representative of the 9 wells on which pumping tests were performed. Because K_z is generally expected to be lower than the horizontal (in the radial direction

relative to the pumped well) hydraulic conductivity (e.g., Domenico and Schwartz, 1992), the ratio K_z/K_r was held fixed at 0.1 for the single-well test analysis. The hydraulic conductivity of well skin (K_{rs}) was only estimated when the fitting improved and the estimated K_r was reasonable.

Results of Analysis

The best-fit estimates chosen as the representative results are summarized in Table H2-1. Some results for multiple fitting cases are shown in Table H2-2 as an example of the sensitivity of the estimated aquifer properties to the parameters held fixed. The results for six fittings to EW1 test data are shown: two that estimated all parameters based on data from EW1 plus the observation wells simultaneously, two that used data from the observation wells only, and two that used data from all wells but with some parameters held fixed. The representative K_r is 404 ft/day based on the best fit; this high conductivity of the aquifer explains the flat time-drawdown curves (i.e., reflecting steady flow condition) recorded during the test. The other parameter estimates are also reasonable (Table H2-2). The drawdown response during the test (flat time-drawdown curve) and the estimated K_r are in agreement. The test analysis results supersede the visual description of the lithology of the screened interval at EW1; the pumping test results are representative of coarse sands but the lithologic description for EW1 includes silt, fine to medium sand, and clay within the screen interval. The visual lithologic description for EW1 is likely biased toward fine grained soils, because the downhole resistivity log and boring log for nearby MW8 indicates predominantly sands. The estimated K_z/K_r values were low, representative of the layering in the aquifer with alternating coarse and fine-grained soils (i.e., sands and silts/clays). Such low K_z explains head differences between shallow and deep-screened wells (e.g., at MW8A-D) and is expected to limit downward migration of contaminants.

The overall range of K_r values estimated from the MW26B test is 316 ft/day to 383 ft/day. The results of the sensitivity simulations for the MW26B test show that whether S_s or hydraulic conductivity from well skin (K_{rs}) were estimated or fixed, or whether K_{rs} was omitted (no skin) has little effect on the estimated K_r . These results increase the confidence in the K_r estimate.

The model fit to the test data was good. Slight systematic misfit for some wells could be explained by pumping rate measurement errors in some test steps, leaking pump valve during recovery, and non-ideal response of the aquifer (e.g., heterogeneous aquifer properties, etc.).

The representative K_r results range from a minimum value of 45 ft/day at MW27B to 404 ft/day for EW1. The K_r values are higher than those estimated from slug tests on the same wells. This is a common test outcome; because the hydraulic disturbance caused by pumping affected much larger volume of the tested aquifer than the disturbance from the slug tests, more flow pathways (i.e., zones of relatively high K_r) were active during the pumping than during the slug tests. K_{rs} was calculated for five of the nine test wells; the skin effect was insignificant for the remaining wells. The average specific capacity is 62.2 gpm/ft and the average well loss coefficient (C) is 0.3 min²/ft⁵.

References:

Kawecki, M.W. 1995. Meaningful Interpretation of Step-Drawdown Tests. *Ground Water*, vol. 33, no. 1, pp. 23-32.

Kruseman, G. P., and N. A. deRidder. 1994. *Analysis and Evaluation of Pumping Test Data*. International Institute for Land Reclamation and Improvement, Wageningen, Netherlands, 377 pp.

Perina, T., and T.C. Lee. 2006. General well function for pumping from a confined, leaky, or unconfined aquifer. *Journal of Hydrology*, vol. 317, no. 3, pp. 239-260.

Table H2-1

Pumping Test Results using GWF Method of Analysis

Omega Chemical Superfund Site

Well	K_r (ft/min)	K_{rs} (ft/min)	C (min^2/ft^5)	S_s	R^2	specific capacity (gpm/ft drawdown)	K_r (ft/d)
MW23A	0.148181	0.00702882	0.13423	4.00E-05	0.997687	5.0	213
MW24A	0.23749	N/A	0.0395194	4.00E-05	0.983168	139.2	342
MW24C	0.177324	0.00624687	0.0636532	4.00E-05	0.998679	52.9	255
MW26A	0.12908	N/A	0.0629765	4.00E-05	0.988662	104.4	186
MW26B	0.219279	N/A	N/A	4.00E-05	0.921618	85.6	316
MW27A	0.037196	0.0071075	0.685561	4.00E-05	0.992678	15.8	54
MW27B	0.031515	N/A	0.796796	4.00E-05	0.985161	14.3	45
MW30	0.200749	0.0122843	N/A	4.00E-05	0.999379	80.6	289

Well	K_z/K_r	K_r (ft/min)	S_s	K_{rs} (ft/min)	C	R^2	K_r (ft/d)
EW1	0.009198	0.280757	2.0700E-05	3.03E-03	1.88E-01	0.99958	404

Notes:

 K_r = Hydraulic Conductivity of the aquifer K_{rs} = Hydraulic Conductivity of well skin C = well loss coefficient S_s = Specific Storage K_z/K_r = anisotropy ratio where z is vertical and r is horizontal

N/A = Not considered in the model.

gpm = gallons per minute

 S_s was fixed for monitoring well pumping test analyses at 4.0E-05 K_z/K_r was fixed for monitoring well pumping test analyses at 0.1

Table H2-2

Pumping Test Results for MW26B and EW1 using GWF Method of Analysis
Omega Chemical Superfund Site

Well	K_r (ft/min)	K_{rs} (ft/min)	C (min^2/ft^5)	S_s	R^2	specific capacity (gpm/ft drawdown)	K_r (ft/d)	
MW26B	0.219279	N/A	N/A	4.00E-05	0.921618	85.6	316	
MW26B	0.266092	4.00E-02	N/A	3.90E-04	0.927354	85.6	383	
Well	K_z/K_r	K_r (ft/min)	S_s	K_{rs} (ft/min)	C	R^2	K_r (ft/d)	comments
EW1	0.009198	0.280757	2.07E-05	3.03E-03	1.88E-01	0.99958	404	used all data
EW1	0.006863	0.316942	1.00E-06	3.03E-03	1.88E-01	0.999628	456	used all data
EW1	0.024621	0.181944	1.74E-05	2.00E-03	N/A	0.960375	262	used observation wells only
EW1	0.019255	0.187472	3.85E-05	6.96E-03	N/A	0.984698	270	used observation wells only
EW1	0.1	0.137665	9.74E-05	3.58E-03	1.89E-01	0.999443	198	used all data, fixed K_z/K_r
EW1	0.018632	0.174987	4.00E-05	3.40E-03	1.89E-01	0.999546	252	used all data, fixed S_s

Notes:

K_r = Hydraulic Conductivity of the aquifer

K_{rs} = Hydraulic Conductivity of well skin

C = well loss coefficient

S_s = Specific Storage

K_z/K_r = anisotropy ratio where z is vertical and r is horizontal

N/A = Not considered in the model.

gpm = gallons per minute

S_s was fixed for monitoring well pumping test analyses at 4.0E-05

K_z/K_r was fixed for monitoring well pumping test analyses at 0.1

